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**VA-U:**

**Addressing the gaps in respiratory protection through a  
holistic open-sourced design alternative**

Aishwarya Uniyal

Rochester Institute of Technology

A Thesis submitted in partial fulfillment of the requirements for the degree of

Master of Fine Arts in Industrial Design

The School of Design

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Thank you everyone, once again.

## Abstract

With industrialization and urbanization, more populations, whether at the workplace or outside in the streets, find themselves exposed to contaminated air. Respiratory hazards and illnesses arising thereof are prevalent across most industries and economies. Beyond developed economies with strong labor laws, a large part of the workforce faces the lack of access to respiratory protection, which also is evident in the gaps of knowledge of its correct use. Even among the groups with access to respirators, incorrect use arising out of miscommunication or comfort is common. Evaluating the design and use of the different types of respirators while also studying the contrasting laws, availability and attitudes towards safety in different markets through surveys and interviews, the author has identified the area of cheaper respirators and dust masks to be the most used, and misused. Exploring alternatives of filtration, components, construction and material, a fabric-based product design with an open development process is proposed with the intent of increasing access to and addressing main comfort issues of users at that price range. Another aspect of the solution is visual communication which aids in educating and also identifying the correct respirator for the application. This solution is intended to fit into the existing system with recommendations and review of regulatory bodies - that also functions as a channel for the authorities to be aware of the innovations happening outside of controlled environments for realistic scenarios. The simplicity of the design also makes it feasible for the manufacture of this respirator at both small and large scales. The ease in availability and its compact design also makes it ideal for situations with a surge in respirator demand, as in the case of natural or manmade disasters.

*Keywords:* respiratory protection, PPE mask, open-source design, respirator, industrial design

## Introduction

Breathing, as a physiological process, is also one which is an ever going and a necessary two-way exchange where the insides of an individual can be considered to be literally exposed to and interfacing with the environment. Any impact on respiration or air quality quickly cascades and affects other physiological processes.

Mankind's progress has increasingly exposed people to respiratory hazards in the work environment - be it a mine, an indoor office space,<sup>1</sup> or even an additive manufacturing lab.<sup>2 3</sup> This, paired with rapid urbanization has affected the air quality of population centers,<sup>4 5</sup> also creating a potential for massive effects in natural and manmade disasters.<sup>6</sup> While the aforementioned progress has also allowed us to protect ourselves better against degrading air quality through respirators or air purifiers, the mask or the respirator truly has become an appendage of the modern man - such a product, thus, definitely requires a deeper look which isn't just limited to its filtering performance.



*Figure 1. Respiratory protection finds requirement in daily life and at work*

*(Photos by: Anna Shvets, CDC and Pixabay)*

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<sup>1</sup> Wyon D. P. 2004

<sup>2</sup> Chan, F. 2017

<sup>3</sup> Stefaniak A.B. 2019

<sup>4</sup> Marlier, M.E. 2016

<sup>5</sup> Molina 2004

<sup>6</sup> Gu, D. 2019

For workplace environments, even with the existence of respiratory hazards across developing and developed economies, there are sharp differences in attitude and awareness towards safety<sup>7</sup> which ultimately reflect in their safety regulations.<sup>8</sup> This also correlates to the research and development pertaining to respirators and their availability in a society.<sup>9</sup> Having experienced this contrast first hand, between the author's home country of India and the USA, our comparative research involving market surveys and user interviews verified the differences and highlighted improvements needed to both the system and the product. We also identified the greatest amount of misuse and lack of knowledge in the class of respirators meant for general purpose (large dust particulates and such).

By evaluating the existing products, both certified and alternatives, for comfort (a key determinant for incorrect use) and construction details, we were able to identify the key design details of a respirator and the tradeoffs related therewith. A qualitative focus on these respirators was in line with the design approach of keeping the user at the center of the process, helping us identify the issues the design would address. We also briefly discuss how the COVID-19 pandemic made the discussed issues with respirators and masks salient.

Knowing the imperfections and tradeoffs of any respiratory PPE, we try to relate and classify these interrelated and complex problems spanning multiple levels. From these observations, a solution is proposed, as a new class of respiratory protection which brings the best of the already used alternatives to the table. It serves as a template for product development in an open-sourced way creating a channel between the users and the other stakeholders that develop and regulate respiratory protection measures. The product design focuses on minimizing components and cost, using locally available material and simplifying assembly with a unique new donning and mounting method. We also suggest improvements to better visually communicate correct use and its nuances, which otherwise get lost in translation or context.

## Problem Overview

Among the areas in occupational safety, respiratory hazard is the kind which spans industry and economies, having both long and short-term impacts on the health of the workers. Respiratory protection also often finds the non-worker population as a user, and access to it and knowledge of correct use differs sharply between developed and developing nations. Incorrect use and even an absence of use in most general situations requiring respiratory protection is common regardless and is mostly related to comfort. Alternatives both effective and ineffective are also the most prevalent in this range. A solution which addresses the above-mentioned problems while providing a base level of respiratory protection thus becomes necessary.

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<sup>7</sup> OECD Data

<sup>8</sup> Singleton, W.T. 1983

<sup>9</sup> ISEA Member Listing



## Research

With a focus on the United States and India, we explored literature on worker health, illnesses and safety, especially pertaining to respiratory protection. Also looking at existing laws (or lack thereof) and the markets in both the countries along with the regulatory processes and bodies gave us a framework to work within. We also had conversations with workers with varying familiarity levels with respirators in both India and the US. To benchmark and evaluate the available respiratory PPE options against each other, we also used different kinds of approved respirators and their alternatives.

## Background

With OECD countries having more reliable data, mining, manufacturing and construction rank highest in both occupational injuries and fatalities.<sup>10</sup> These are also the fields which comprise the large part of the organized labor overall in these countries. Specifically, for the US, OSHA states that there was a drop in worker fatalities from 14000 in 1970 to 4340 in 2009, despite a doubling of the workforce. This is also evident from a decline in injuries and illnesses from 11 per 100 workers in 1972 to 3.6 per 100 workers in 2009.<sup>11</sup> The numbers for India, despite being variable across sources remain higher compared to the US, vary heavily with a large part of injuries and deaths being underreported, and weak labor laws enabling a large unorganized labor industry.<sup>12 13</sup> Unlike the detailed laws and their enforcement in the US, India has a handful of labor protection laws which are weakly enforced.<sup>14</sup> However, there has been a slow legislative move towards consolidating and strengthening the laws and their enforcement as the country develops economically.<sup>15 16 17</sup>

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<sup>10</sup> OECD Data

<sup>11</sup> OSHA Data

<sup>12</sup> Bakshi, H. 2017

<sup>13</sup> Yadav, S.S. 2019

<sup>14</sup> Sardana

<sup>15</sup> International Labor Organization 2013

<sup>16</sup> Ministry of Labor and Employment, Government of India

<sup>17</sup> Ministry of Labor and Employment Committee, Government of India



Figure 2. Developing nations lack the basics when it comes to worker safety

(Photo by: Imre Solt)

After on-site fatalities and injuries, chronic diseases of the lung make up almost a third of all worker related deaths reported globally across industry sectors.<sup>18</sup> About 30 percent of Indian steelworkers engaged in tasks like casting/molding, gas cutting, welding, forging, grinding, and painting/nickel plating, reported one or more problems like coughing, frequent phlegm, wheezing and breathlessness.<sup>19</sup> An overall comparison of work-related health problems in Indian informal work sector also clearly states the high rates of respiratory illnesses in industries other than steelwork.<sup>20</sup> Among developed economies, the WHO reports that exposure of organic dust, microorganisms, bacteria, fungi and molds along with chemicals put 15 percent of the workers at risk to illnesses like allergies, fibrotic responses and pneumoconiosis. These effects also compound to impact the company and the nation economically.<sup>21</sup> Cases from Russia point to an occurrence of respiratory diseases among 42 percent of the workers employed in the wool industry.<sup>22</sup> There are also occupational respiratory illnesses attributed to specific professions - farmer's lung, bird watcher's lung, coal miner's lung and also the WTC lung, which was the long-term impact to the first responders and people present in 2001 World Trade Center Attacks.<sup>23</sup>

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<sup>18</sup> Speizer 2006

<sup>19</sup> Singh 2013

<sup>20</sup> Nag 2016

<sup>21</sup> WHO-GARD

<sup>22</sup> Manuilenko 1990

<sup>23</sup> Li 2019



Figure 3. Above – Worker sanding and grinding metal in a factory in Aligarh, India (Photo by: Author)

Below - Worker welding with minimal protection (Photo by: Dhananjay Ringe)

Looking at the mortality data shared by the National Institute for Occupational Safety and Health (NIOSH) in the US related to respiratory illnesses, it can be clearly seen that the deaths are the highest in fields like mining and construction,<sup>24</sup> where the hazard does not show immediate effects and hence leads to long term exposure. These are also the environments where regular respirators are advised to be used and it isn't as lethal to not wear one as compared to, say, a spray booth with highly volatile carcinogenic compounds (the effects of which are almost immediate - lightheadedness, nausea etc.) It must also be noted that concentrations of larger particles suspended in the air are higher in these domains.<sup>25 26</sup> While simple protective respiratory interventions have shown considerable

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<sup>24</sup> NIOSH – Division of Respiratory Disease Studies 2007

<sup>25</sup> Muleski 2005

<sup>26</sup> Gupta 2019

benefits to individuals' cardiovascular health,<sup>27</sup> violations of incorrect use are still common comprising half of the citations noted in inspections - that too being higher in industries with less lethal and larger particulate exposure.<sup>28</sup>

## On Respiratory Protection

**System.** We will use the setup of developing respiratory safety standards and the oversight in the US as the benchmark as it is one of the authorities on setting the safety standards which most major manufacturers have to comply with. It also covers details at multiple levels, right from the product up to its manufacture and distribution. These guidelines and testing standards, or a part thereof, are often used by other countries which do not yet have their own systems set up in place.

In the United States, occupational safety is under the purview of Occupational Safety and Health Administration (OSHA), which develops recommendations, conducts research and develops information for health and safety standards working closely with employers, safety and health professionals, unions and advocates. It regulates safety standards and their enforcement. NIOSH, as an agency under Centers for Disease Control and Prevention (CDC), which works closely with the former, may also "conduct on-site health hazard evaluations to determine the toxicity of materials used in workplaces and fund research by other agencies or private organizations through grants, contracts, and other arrangements - setting and enforcing standards by providing training, outreach, education and assistance. They also provide useful tools to be used on-site by safety inspectors to gauge use employing disciplines like epidemiology, medicine, industrial hygiene, safety, psychology, engineering, chemistry, and statistics.

Designers and manufacturers of respiratory PPE constantly innovate new designs applying new filtering methods, forms or material which are tested by NIOSH in a lab setting on testing models (sometimes tested in private labs) where their sealing and filtration properties are evaluated. The respiratory PPE is approved for sale after it passes the test criteria. There are guidelines on essential information on use, maintenance and storage that needs to be provided with the packaging of the product. It is necessary that the employer provide the respiratory PPE on site if a job has a respiratory hazard, and its fit testing is also a responsibility of them.<sup>29 30</sup> Inspections of sites are conducted for improvement of safety and any violations are notified to the site's safety officers and ways to correct those are strategized - in case of respirators, training on correct use might be implemented.

The National Institute of Occupational Health (NIOH) of India is far behind when it comes to research, data and its availability when compared to its counterpart in the US. Though the Bureau of Standards has recently

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<sup>27</sup> Langrish 2009

<sup>28</sup> Mendeloff 2013

<sup>29</sup> OSHA Bulletin

<sup>30</sup> OSHA Standard

given some guidelines on the design and testing of respirators.<sup>31 32</sup> Small and medium sized operations are unwilling to invest in safety equipment and bigger businesses which risk losing reputation and put some, if not the best, effort in the safety of their workers by purchasing ornamental safety equipment.

**Respirators.** The function of a respirator is to prevent the intake of hazardous particles suspended in air by maintaining a seal between the user's airway and the environment while channeling the air through a filtration mechanism. Mechanical filtration, the most common of all methods, creates a physical barrier to the particles suspended in the air. This is either achieved by passing the contaminated air through pores or micro-meshes (regular N95 or HEPA filters), or by using physics of motion to separate out particles by their density (as in cyclone filters). Chemical filtration methods use adsorption or chemical reactions to neutralize and trap a hazardous particle suspended in the air which might otherwise not be trapped by a mechanical barrier. At a larger scale, say in the case of facility ventilation or an air purifier, a combination of multiple methods is used to purify air. But at the level of personal respiratory protection, mostly a single method is applied in consideration of the size and complexity of the product. Though the working principle for most respirators or masks might be the same, the effectiveness is largely driven by the material and the design - i.e. a regular fabric might also filter the air as effectively as a certified engineered filter pad but how it is implemented in a product can drastically sway its effectiveness. It is also known that particles larger than 2.5  $\mu\text{m}$  can be easily trapped by most non-woven fabric filters,<sup>33</sup> and even the effectiveness of regular fabrics has been shown in traditional water filtration methods against pathogens.<sup>34</sup>



Figure 4. Examples of different respiratory protection methods - the surgical mask is not considered a PPE

<sup>31</sup> Bureau of Indian Standards 2008

<sup>32</sup> Bureau of Indian Standards 2019

<sup>33</sup> Shakya 2017

<sup>34</sup> Colwell 2003

(Photos of products from manufacturer catalogues)

### ***Types.***

***Certified for Work.*** The types of respiratory PPE available commercially vary primarily in their filter effectiveness, cost and comfort. These three factors are interrelated - effectiveness in filtration through seal, method and fit, which affects the cost of material and its manufacture, which ultimately affects the comfort. The highest of the tier aim to isolate the user from the environment as much as possible and are usually self-contained or have a powered supply of air through an external filtering mechanism.

The commercially available respirators certified for worksite use are:

- Disposable N95 dust masks
- Half face elastomeric respirator
- Full face elastomeric respirator
- PAPRs: Powered Air Purifying Respirators
- SCBAs

Note - Often, medical masks are also mistaken by some users as respiratory PPEs and incorrectly find use as dust masks. Medical or surgical masks technically are respiratory PPEs but are limited to prevention of the spread of aerosols through exhalation or cough/sneezing, we address this issue of miscommunication as well in our solution.

***Alternatives.*** For general use, masks need not be certified by governing bodies and thus the alternatives to the certified respirators are many, they range from products undergoing review and testing right down to DIY masks that can be created with household materials. Some of these are purely focused on the function and address user comfort issues, as in the case of Readimask, which has a single use stick-on-the-face design and is in use by the Dept. of Corrections (samples obtained from one of the inventors). Others, often position themselves as premium products and fashion accessories, as in the case of Vogmask, which sells fabric face masks with replaceable N95 filters.<sup>35</sup> Some design concepts proposed by industrial designers, as in the case of CM1, try to increase filter life (for cost and sustainability) by pairing two or more filtration methods and monitoring them through smart-tech.<sup>36</sup> Other designers and artists have approached respirators from a purely creative perspective where masks are sold more as a fashion statement, made from repurposed shoes.

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<sup>35</sup> Vogmask Website

<sup>36</sup> Pfuner, E.T 2016



Figure 5. Some respiratory protection alternatives using everyday materials

(Photo top-left and right: News18, Photo bottom-left: Mr. Hacker)

Apart from these commercially available alternatives and concepts, other mask designs are shared as DIY instructions with common household materials like fabrics and plastic bottles repurposed as emergency respirators - the primary focus of their use is aimed at scenarios like natural disasters, riots, epidemics and such.<sup>37</sup> Though cost and access are the priority in these cases, the filtration effectiveness of some has been tested and proven on ground.<sup>38</sup> When it comes to self-constructed/designed alternatives, rather than being dismissed or overlooked, we will consider them as actual respiratory protection because of their prevalence and utility. Coming down to the simplest of all solutions, a plain cloth or a wet towel, has been shown to be effective when moistened and rolled up to cover the mouth - an advised respiratory protection during housefires where it can manage to trap most large smoke particles.<sup>39</sup> Wrapping cloth around one's face is still the simplest and hence the most common way of respiratory protection across the unorganized sector and in developing nations overall. This is even observed in situations which are free from oversight, say a small workshop or a home-setting, or areas in a disaster with strained supply chains. This can be effective against larger dust particles and has naturally found its use to be prevalent in cultures across the world as an accessory or a part of the local attire. The *gamcha* is one such cloth, finding multi-purpose use, it also doubles up as a dust protection cover for the nose and the mouth. It is pretty much at par with homemade filtration methods like a *keffiyeh* or a simple bandana tied around the face.

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<sup>37</sup> Jeffrey 2017

<sup>38</sup> Brushwood 2016

<sup>39</sup> Mueller 2018





Figure 6. Worker with a cloth tied around his face on a steel-grinding and cutting task

(Photo by Dhananjay Ringe)

**Design and Manufacture.** The form of respirators is deduced from laboratory models and standards set for a range of sizes which are based on anthropometric data. The classification of respirators is deduced from their filter performance, according to 42 CFR Part 84.<sup>40</sup> The form of the alternatives is usually driven by a more locally relevant template (say a European mask manufacturer would use measurement data suitable to a European user) or the user using their own measurements as a reference for DIY solutions. The form also affects the complexity of the respirator which decides the material and its construction but for most simple masks, the working principle is to secure the filtering material as tightly against the user's face as possible (with some space for comfort of course). While the cheapest respirators are meant to be disposable, the higher cost versions usually come in a modular setup of the reusable facepiece and the filter cartridge.

For the creation of alternative masks, any material from one's surroundings is usually suggested with an emphasis on household materials or repurposed objects. Since the user puts down their own measurements, usually the resulting respirator is highly customized - sometimes base template values are given. Apart from a simple cloth tied to the face, other respiratory protection methods need additional material use and construction-assembly steps. The surgical mask, though not a traditional respiratory PPE, uses a non-woven fabric (which acts as the barrier and structural layer) backed by a mesh secured at ends to a braided elastic polyester loop. For a disposable dust mask, a more complex method is used where non-woven fabric layers are thermo pressed into a cup-like shape secured at ends with a heat-sealed non-adjustable polymer strap. Both of these masks have a metal nose clip which forms to the area over the user's nose.

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<sup>40</sup> CDC-NIOSH





*Figure 7a. Studying the material and assembly details of an N95 dust mask*

*(Photos by Author)*

Some commercial fabric masks for non-work use have a washable stitched fabric that acts as a structural mount for the replaceable filters. Often, low-tier respirators offer exhalation valve options for heat, humidity and to counter carbon-dioxide buildup. Other commercially available alternatives, like Readimask, meant for quick use are a combination of the filter and an adhesive that sticks to the skin, sometimes accompanied by a plastic screen to protect the eyes.



Figure 7b. Construction and design details of low and high tier masks

(Photos by Author)

The higher-tier respirators have a reusable facepiece with replaceable cartridges. The elastomeric facepiece is cradled by a contraption of adjustable straps which secure and tighten around the user's nose and mouth - over the back of the head, the back of the neck. It has two valves into which filter cartridges of choice can be used. The components are injection molded to lock into assemblies of high tolerances - high quality specialized polymers are used to counter wear and tear, exposure to corrosive elements and sprays. The rubber or silicone lining secures onto the face while also pushing up against the skin forming an effective seal. Silicon facepiece along with contoured sealing flange and cradle suspension system. The cartridges can be selected for simple dust applications and really fine vapor situations, and are often paired together for special use cases. There is some standardization on color coding for cartridges to identify them for an application,<sup>41</sup> but there is no interchangeability between brands.

As the respirator gets used, its filtering ability drops with more particles it traps and breathing through it also becomes difficult. To convey the end-of-service life in cartridges, a visual indicator (often a color change) may appear - in more advanced respirators, alarms are programmed to go off if the filtering capability drops below a certain level. To be on the safe side, many respirators have cartridge replacement or change-out schedules which the

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<sup>41</sup> NPPTL 2008

manufacturer recommends. In simpler respirators, if the mask seems to be visibly damaged, soiled or contaminated (dust stains etc.), it is advised that it be discarded.<sup>42</sup>



Figure 8. Packaging details of different tiers of respirators

(Photos by Author)

The packaging of the products also differs where the lower-tier respirators are available in clamshell packaging while elastomeric half face respirators come in polymer bags with a zip-lock type mechanism intended for storage. For commercially available fabric masks, a cleaner visual language is observed in the upper price ranges, while it can go down to light plastic stick-on packaging, with minimal or no information or labelling, in cheaper products.

A few manufacturers of such respirators, whose products are approved by NIOSH, are - 3M, DuPont, Kimberly-Clark, One-Fit, SAF, Freedom, Blue1, Honeywell North, MSA and Gerson. Apart from masks made by obscure manufacturers, no such major manufacturer respirators or above was found in India but there are some companies which do manufacture lower-tier dust masks - Alok Industries, JCT Phagwara, Gokaldas Exports, Aditya Birla.

<sup>42</sup> NIOSH Website

***Access and Availability.*** Getting a respirator of desired choice is not a hassle in the United States, where one can drive to a nearby hardware store like Lowe's or Home Depot, or just order it from online portals. The range and availability fit any budget and requirement spanning jobs like simple woodworking to working with automotive epoxy resins and paints. The staff at these stores is relatively well knowledgeable about respirators and their correct applications and classifications. Prices range from a couple of dollars to several hundred dollars with the availability of replaceable components and consumables. Alternatives are often observed outside of a worksite, away from regulatory enforcement, mainly used for comfort or cost by the non-worker populations. These, too, are commercially available masks with a higher level of filtration than a cloth tied to the face - some even have approval from the Food and Drug Administration (FDA) or foreign equivalents of NIOSH.

In India, the absence of such hardware outlets makes surgical masks sold at the neighborhood chemist stores the only form of respiratory protection immediately available. There are no physical stores that specialize in selling hardware equipment except for a few online retailers (Industry Buying / Alibaba) that supply in bulk. Since manufacturing is not local, the costs are higher and the lower wages make the lack of access more pronounced.<sup>43</sup> In situations requiring immediate respiratory PPE, most workers have to improvise with whatever they can cover their faces with - alternatives, often incorrect for the job, thus, are the mainstream.

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<sup>43</sup> U.S. Bureau of Labor Statistics Data

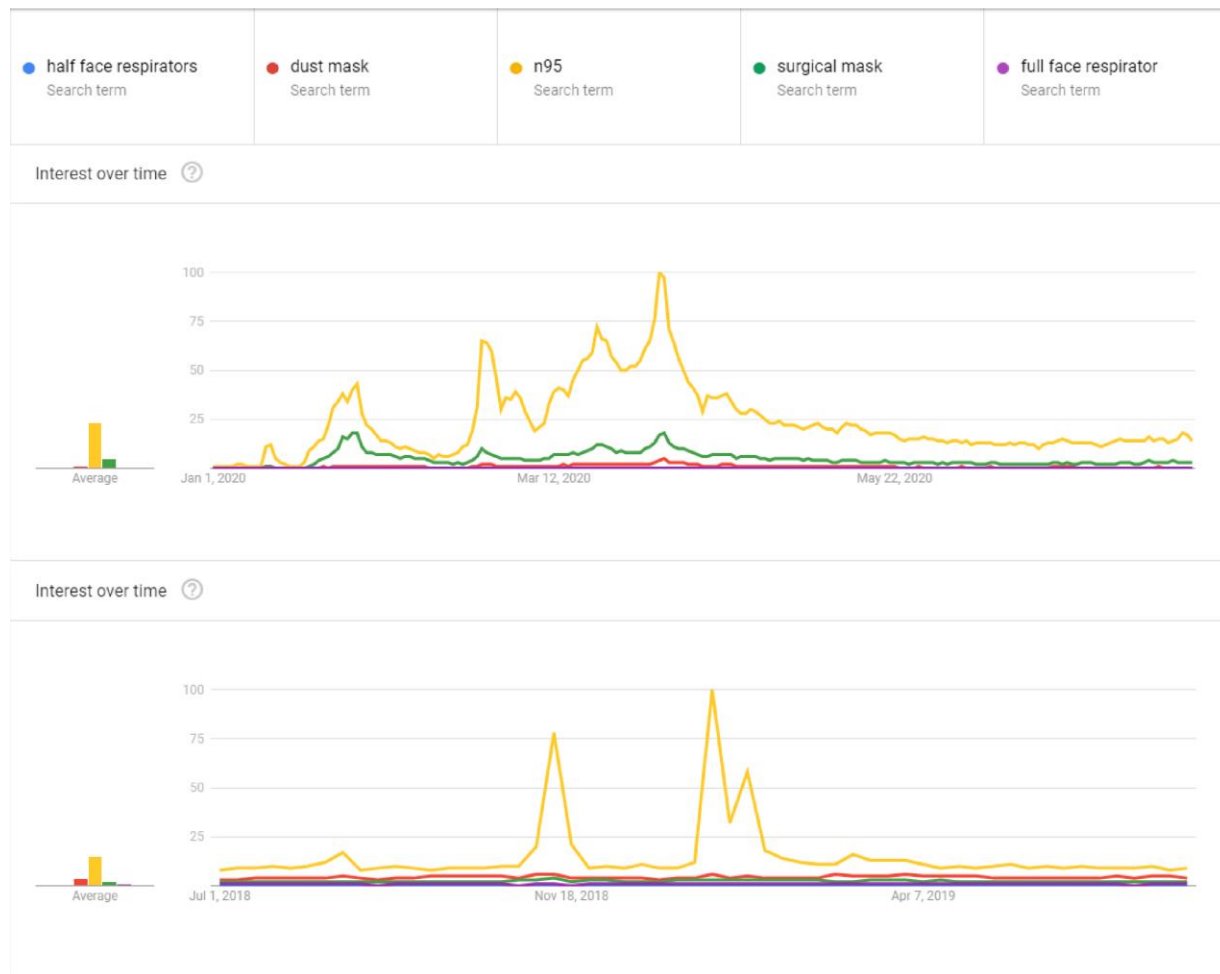


Figure 9. Global search interest of different mask types after (above) and before COVID-19 pandemic.

(Data generated from: Google Trends)

Overall, across the world, the sales and demand for respirators is the highest among the disposable N95 and dust mask bracket (demonstrated by global search results)- which makes sense as a large part of the jobs lie in the environments with particles that these can protect against.

**Known Issues.** In the hierarchy of hazard controls, PPE sits at the bottom being the least effective among other measures, as even if the ideal equipment is designed, the user behavior ultimately decides its effectiveness.

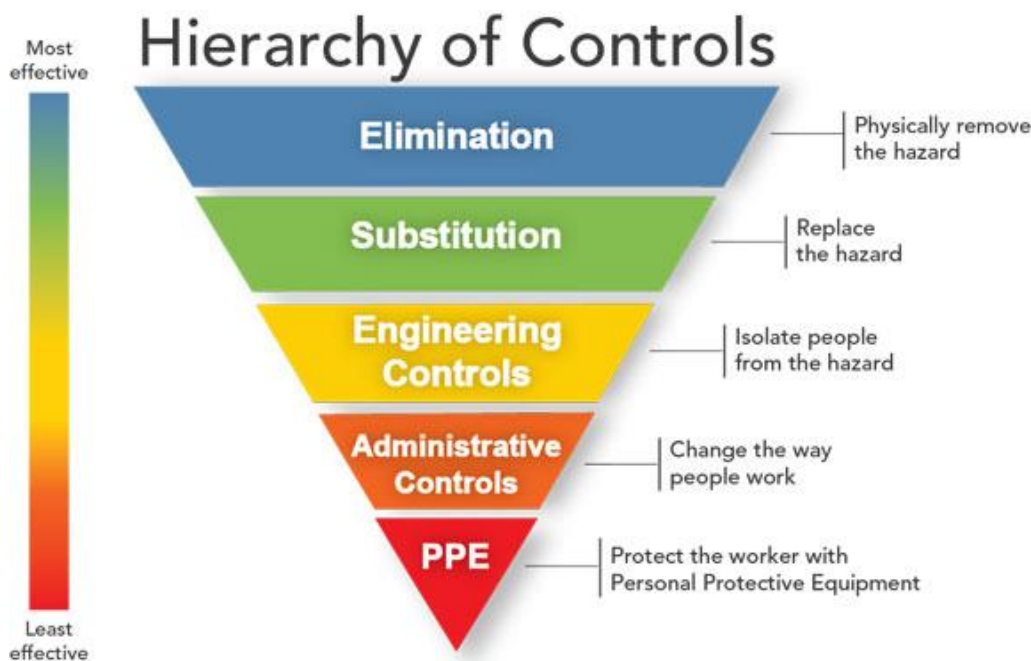


Figure 10. Hierarchy of hazard controls

(Diagram by NIOSH)

Leakage, through face seal and filter medium, is a key issue which leads to respirators being ineffective.<sup>44</sup> The prescribed dust masks for these common scenarios are designed for a general fit and end up not forming an effective seal around the face where up to 89 percent losses have been observed to occur at the region around the nose.<sup>46</sup> The presence of facial hair also impacts the sealing effect of these masks<sup>47</sup> - this has also been a widely mentioned topic among interview subjects, where not many would be willing to shave to use a respirator, and it has also been a part of certain debates on safety, religion and personal choice.<sup>48</sup> Though fit and seal tests might be required in a timely manner, every time there is a change in face due to weight gain or loss, dental work, face surgery or scarring, a new point of failure arises which might go unchecked in between test schedules.<sup>49 50</sup>

For heat and humidity within the masks, exhalation valves are provided in more sophisticated respirators, but leakages were attributed to dust settling in the valves which prevented proper closing during inhalation rendering the mask useless<sup>51</sup> - the maintenance of elastomeric respirator accounts for this but valved disposable respirators

<sup>44</sup> Rengasamy 2010

<sup>45</sup> Jung 2014

<sup>46</sup> Oestenstad 1990

<sup>47</sup> Holton 1987

<sup>48</sup> OSHA Directorate of Enforcement Programs 2011

<sup>49</sup> OSHA Appendix A to §1910.134

<sup>50</sup> OSHA Appendix B-1 to §1910.134

<sup>51</sup> Bellin 1990

cannot be cleaned. Advanced respirators create a seal by tightly restricting the jaw with the fit which also restricts communication, which is a common user complaint and can impact workplace performance. In metabolically intensive tasks, quick respiration is essential and thus masks become a hindrance.<sup>52</sup> There is also an impact on cognitive tasks caused by respiratory PPE.<sup>53</sup> The effect of masks on work efficiency is studied in detail by Johnson with factors other than breathing, like field of vision & humidity.<sup>54</sup> Along with this, the FAA (Federal Aviation Administration) has also studied the effects of different types of N95 respirators with a focus on speech legibility and obstructiveness with other equipment.<sup>55</sup> Not only does the study show the alarmingly high deterioration of lung function among the industry workers but also highlights the reluctance to wear a mask (among workers engaged in molding/casting sections). Since PPE design does not consider the interaction with other equipment, increased fatigue and risk to injury was reported in the case of firefighters.<sup>56</sup>

Even though the initial stages of the products' life-cycles are relatively well addressed, not much focus is laid on the disposal of respirators with most users not being sure of the kind of disposal. The reusable facepiece of an elastomeric respirator addresses this problem in a way but the disposed cartridges add to the existing garbage problems. Often the respirator material being a recyclable polymer is incorrectly put in regular trash or recycling streams despite being contaminated with hazardous chemicals. At times, a simple wash might be enough to make it fit for the regular waste stream or the contaminant might not be hazardous (say wood dust) - the awareness of this at the user level, even for other equipment, can impact the amount of PPE ending up in the wrong waste streams.

**Information and Communication.** Among the different developed countries, there are categorization standards which differ in their naming conventions. Sometimes these are adopted by other nations with a lack of strong occupational safety framework. Even within a country, there is no standardized communication at a visual level which can effectively explain the kind of respirator needed for a job.

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<sup>52</sup> Seng 2018

<sup>53</sup> AlGhamri 2012

<sup>54</sup> Johnson 2016

<sup>55</sup> Hah et al. 2009

<sup>56</sup> Kiwon 2011





Figure 11. Lack of uniformity in respiratory hazard and protection's visual identity - even as a requirement

(Photos from signage supplier-manufacturer listings)

Communication at the product level pertaining to the correct operation and use consists of long chunks of text on respirator packaging or manual sheets, sometimes with a graphic, detailing correct use cases and tests. It has been noted though that manufacturers of non-certified pollution masks focus more on the clarity of the communication which might also be because of the standards that force the certified manufacturers to put certain content because of regulation. Usage instructions for half face elastomeric respirators are highly detailed and in multiple languages as separate paperwork while most general-purpose information is a part of the packaging for disposable N95 respirators. It is assumed that the user goes through these before using a respirator.



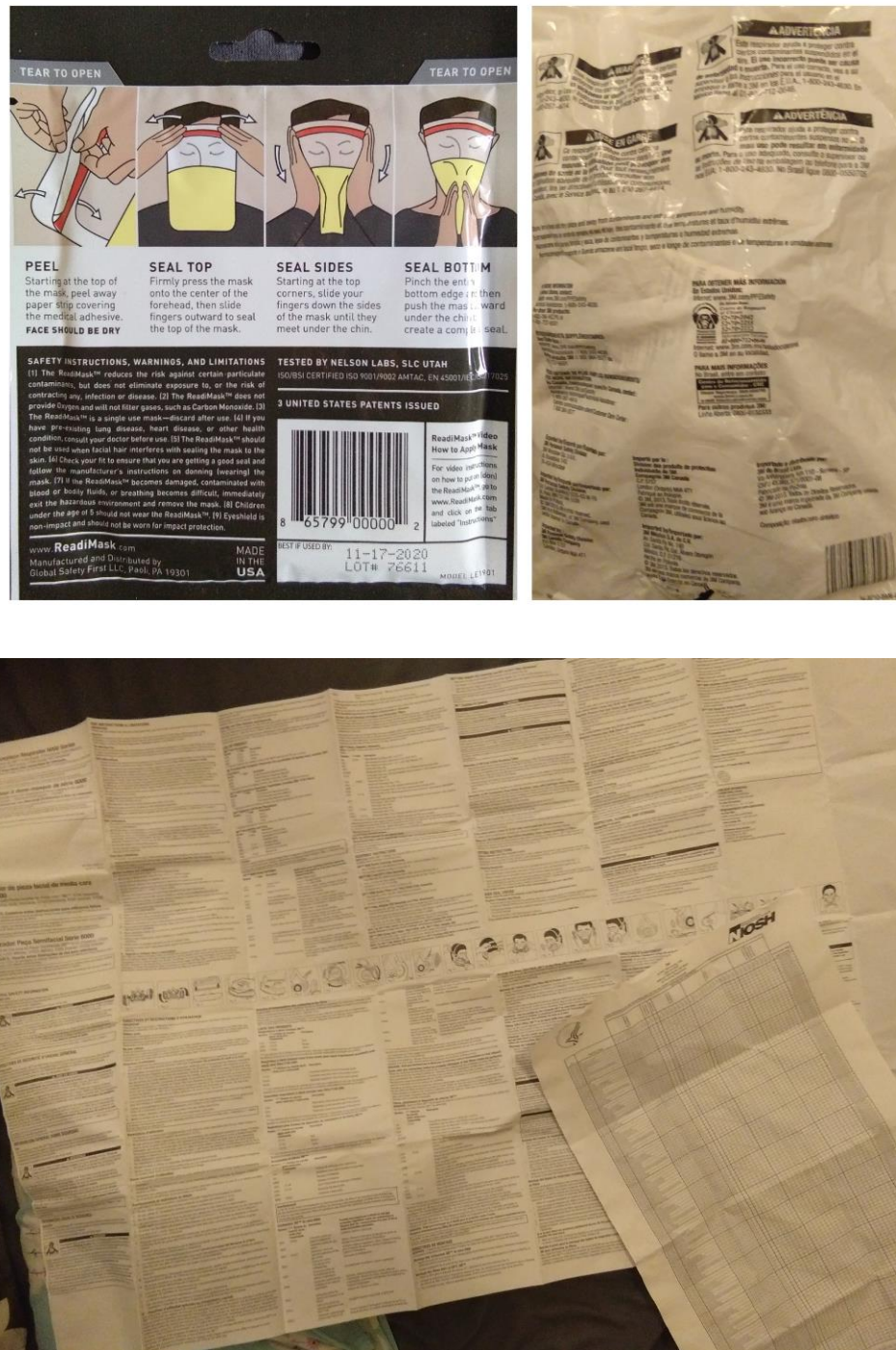


Figure 12. Difference in communication detail and styles between masks (top-left: Readimask; top-right and bottom: 3M half face respirator packaging and inlay)

(Photos by Author)

## Studies

**Interviews - Knowledge, Needs and Behavior.**<sup>57</sup> Interviews of Indian workers, working jobs like spray painting, carpentry, construction and welding were conducted to get their perspective on safety and respiratory protection. Comparatively, interviews with American workers, who are more familiar with respiratory PPE, allowed us to study the lapses in usage and drawbacks of the products being used in tightly regulated scenarios. It was surprising to note that even among highly trained American workers, some sort of incorrect use was prevalent because of misunderstanding or just because the discomfort obstructed their task. In some situations, the workers mentioned not being convinced enough to wear a respirator for a particular scenario ‘just yet’ even while being aware of them being exposed to the pollutants in their environment. We also had conversations with designers and inventors of alternative respirator designs that gave us the pressing issues they were trying to solve through their designs.

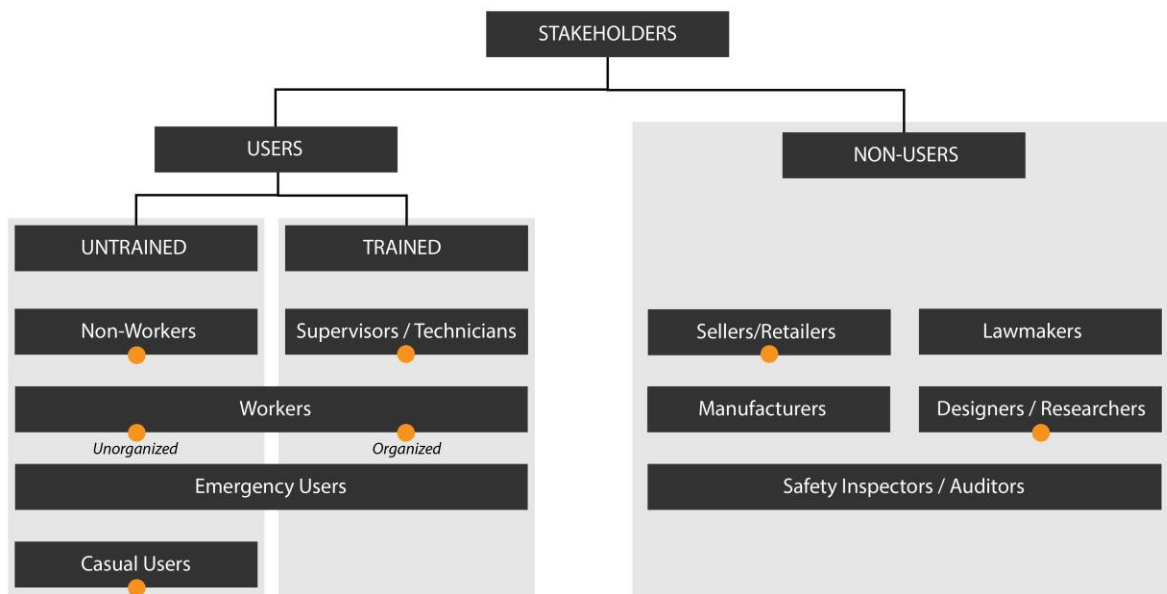


Figure 13. Different stakeholders in a respiratory protection scenario – highlighted groups were interviewed in our research

(Diagram: Author)

Structured as a free-flowing conversation, the questionnaire for US workers focused on their views on regulations and operating knowledge of respiratory protective equipment. They were also encouraged to speak about their experiences with incorrect use they had seen, their own mistakes and how they were corrected. We also touched on the alternatives they have used or the situations when they have foregone respiratory protection for a certain situation. There was some confusion noted about seal and fit tests, with only a safety supervisor knowing the details

<sup>57</sup> User Interviews conducted by Author and Dhananjay Ringe.

of both. Some users of East Asian ethnicities cited difficulties in the fit of respirators to their facial profiles. We also requested a few of our subjects to show us how they stored their elastomeric respirator and to walk us through their donning process.



Figure 14. Interviews with Indian workers

(Photos by Dhananjay Ringe)

For workers in India, the interview questions were simplified down to the minimum (as there is a lack of terminology for respiratory protection) and translated to Hindi. With the aid of the author's filmmaker friend, these conversations were recorded. The interview of Indian workers sought to not only gauge their level of awareness but also study the alternatives they have resorted to use - it illuminated upon the respirator's importance and their own dilemma between comfort and protection.

The problem of heat, humidity & effort required in breathing was common regardless of the individual being asked. Experienced users highlighted some other issues with correct use and its communication. Other pain points were regarding storage, costs of filter replacement, contamination of the filters and interference in use with other PPE or accessories like spectacles and gloves. For US workers, apart from providing interesting views on mask use and the experience, they also expressed their problems with disposal of cartridges of existing masks, inability to use components across brands, hindrance to the use with other PPE and a desire to better gauge the life of the filters when in use. Meanwhile, workers in India are aware of the benefits of masks and respirators but cite comfort, access and costs as the primary reasons for not using this equipment. Surprisingly, the issues highlighted by trained respirator users were the reasons why their Indian counterparts would forego using a respirator. That said, even with the given resources and regulations, workers in the US prefer to avoid the use of masks for most general tasks at hand and some have never performed nor known about the fit tests and seal tests on the respiratory PPE they own. The alternative, despite not being the right respiratory protection for the application, still was a favorite for both its replaceability as well as reusability. There was also the issue of storage, as many users have tried to zip lock their disposable masks as they do to their cartridges to increase its life. Some casually store them with rest of the equipment which may or may not be contaminated - this is more common with half face respirators which have a

rigid form and will not be crushed by the other tools in the bag. There was also the issue of temporary storage, in between use, without exposing the inner area of the mask to the contaminants in the air.



*Figure 15. Storage scenario of a respirator - not the best way to store one.*

*(Photo by Author)*

**Indian Market Surveys - Availability.**<sup>58</sup> To gauge the level of knowledge of the business owners and look at the products and brands available in the shops, we devised and conducted a quick walk-in survey. It had to be simplified down to the detail to get a preview of the inventory, it was also noted that the shopkeepers used different terms to refer to the masks and only a few had the respirators. Surgical masks were more common and any other mask or respirator was basically a fabric respirator with replaceable filters sold as pollution masks. The N95 disposable dust mask was not found in any of the stores. This however has changed since the onset of the COVID-

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<sup>58</sup> Market Survey conducted by Author and Sheenu Kala.



19 pandemic. This market survey confirms and highlights the huge difference between the availability of respiratory PPE in the US and India, as well as the gaps in the general understanding about respiratory PPE.



Figure 16. Various masks available in stores in India – none ideal for the workplace.

(Photo by Sheenu Kala and Sonali Saklani)

**Comfort: Usability Among Respirators.** To test for comfort and performance, both conventional respirators and non-conventional masks were used for extended periods of time, in a scenario other than a lab - this allowed for salience of factors like moisture buildup by exhaled breath and perspiration, dead air space, heat, sensitivity to pressure around the ears. Other actions were also studied, on how the user familiarizes themselves and interacts with the mask. The degradation of the mask itself was also considered with prolonged periods of use. It must be noted that the author used the products in an environment that was free from harmful particles, at home, with the seal/filtration tested using saw dust particles and eucalyptus lotion. These quick tests gave some qualitative data on the different kinds of masks available to an average user. We focused only on the most commonly used respirators/masks, as we are addressing the problems pertaining to masks meant for larger particulate applications.

**Conventional Masks.** Taking the most commonly found N95 dust mask (without an exhalation valve) freely provided by RIT to students and workers in workshops/labs, a usability test was conducted over the period of one week where it was worn for six hours every day while the user engaged in various non-strenuous activities. We also tried out an elastomeric respirator for a similar time period while also observing other users putting it to actual use in a spray booth. The observations could be summarized as:

N95 Dust Masks:

- Warmth and humidity
- Itching (prominent when conscious of the mask)
- Pain caused by straps over the ear region
- Leaks: exhaled air into the eyes
- Jaw movement broke the seal: the mask bent to open gaps
- Jaw movement made the mask slip out from under the jaw to over the chin
- Deformation on turning one's head
- Took off the mask for sneezing
- The filter degraded quickly from inside-out because of moisture.
- Lack of areas on the mask to hold when handling it (ideally should not have contact).
- Required a hard casing for storage.
- Muffled verbal communication.

Half face elastomeric respirators:

- Too sweaty and hot.
- Tightness against the skin.
- Strained breathing relative to dust masks.
- Left a mark on the face.
- Keeping track of filter life is difficult.
- Proper donning took time to memorize.
- Need to perform a seal test. Fit test not readily performable.

Even though the surgical mask is not exactly a PPE, it was also tested and worn for extended periods of time just as a pseudo benchmark, we decided to see why people go for it even when they have the choice of using a disposable dust mask. It was lightweight with little irritation against the skin, however with extended periods of time, pressure on the ears did lead to discomfort and pain.



Figure 17. Testing simple masks for comfort.

(Photo by Author)

**Non-Conventional Masks.** Apart from other fabric-based masks, the closest that comes to them is the disposable Readimask which sticks to the contour of the face with an adhesive and allows for use with spectacles. Two such masks were tested in a wood workshop and at rest for about three hours.

#### Readimask Half Face Usability Test

- Comfortable as no pull around the ears etc.
- didn't feel hot or sweaty.
- exhaling caused goggles to fog.
- formed a good seal.
- Didn't interfere with glasses.
- Wondered if adhesive could be cleaned for reuse.
- Mask felt damp after an hour of use.

We also used a full-face variant of the mask and some observations were as follows:

- Easy to wear
- Smell of plastic
- screen doesn't fog
- Good seal
- Adhesive on the forehead felt ineffective with sweat buildup.
- The face shield doesn't fog but glare interferes with vision.
- On a light beard, the hair gets pulled on by the adhesive.
- The mask felt damp after an hour of use, could not tell if it was sweat or moisture in exhalation.
- Jaw movement is restricted.
- started getting some fogging on the bottom crease of the screen.

We also constructed a DIY facemask reusing plastic bottles and while the seal was effective, the comfort, in terms of contact against the skin and the bulkiness was not a match in front of the above discussed respirators/masks.

**Seal: Visualizing Deformation.** As most testing for leaks is conducted on static models and setups, seal deformation leading to leakage in regular use of disposable respirators is common. This study focused on the deformation of an elastic seal around different facial structures with jaw movements taken into account.

Two strips of foam were affixed over the nose and under the jaw of the subjects respectively. The participants were asked to hold the upper seal and the lower seal in the same position as they had held with no jaw or facial muscle movement, then they were asked to simulate different speaking and facial expressions. When held at two points, representing the clip and the strap, while affixed to the area below the chin, points of failure could clearly be observed by the large deformation of the foam. The most deviation happens around the region of the lower jaw, which causes creasing or folds in disposable dust masks thereby opening entire seals. The original & deformed seal contours are shown with blue and red colors respectively. The images with different contours are superimposed for the same user where the change can be easily observed.

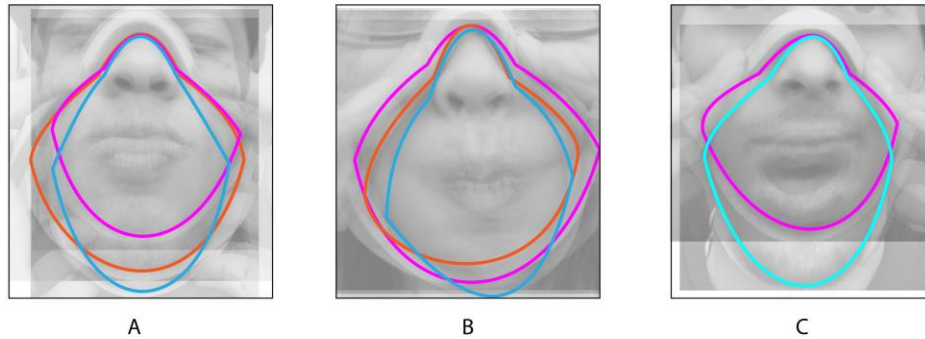


Figure 18. Visualizing seal deformation by super-positioning images (Photo by Author)

Though not a highly controlled study, it does give us an estimate on how the seal fails across different facial profiles and jaw positions. It was also realized that this method only gives us a two-dimensional representation of the deformation, thus, a more detailed study with 3D mapping could be conducted to get values on the amount of deformation. Further work could give insights on deformations in other situations and even specific to different genders and races.

**Fit: Recording Facial Anthropometrics.** Taking this line of thinking further, we wished to quickly and effectively survey the facial anthropometrics of a group of people to highlight the regions of major differences in facial features mapped to a regular mask/respirator's seal region. A visual data plot of points is obtained which shows the convergence and divergence of certain facial features across races and genders.





Figure 19. Quick method to acquire facial anthropometrics (Photo by Author)

This study works by asking the subject to tie a 20"x21" handkerchief over their face like a bandana. The handkerchief is diagonally folded and the midpoint of the diagonal is placed over the bridge of the nose such that the remaining ends go comfortably over the ear to be tied behind the head. Different colors are used to mark different features for every individual this method is repeated on. The features marked are: the chin, the nose, under of the nose, jawline, ears. Alphabetical codes can also be assigned to these features. When spread out, the points give us an estimation of these features laid out on a flat plane which can be folded upon each other to achieve more points arising out of asymmetry.

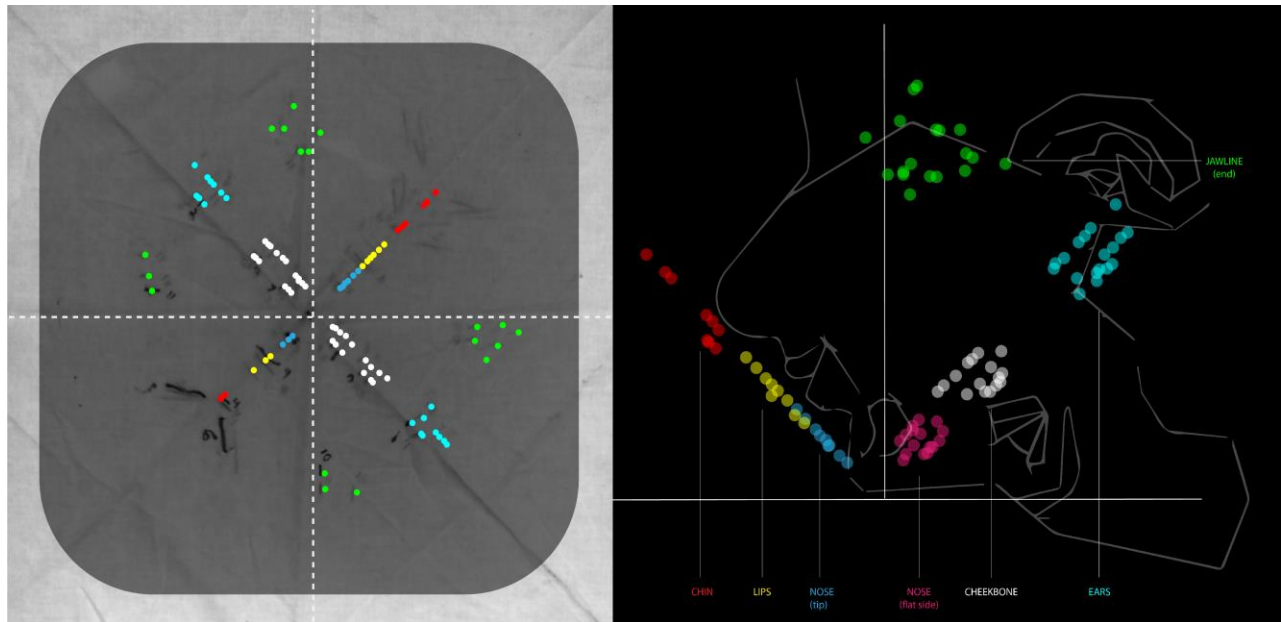


Figure 20. Data points on a plane map to obtain aggregates of facial features

(Photo by Author)

It is obvious that a more controlled repetition of this study with a larger and cleaner dataset will be beneficial to engineering teams. This study later forms the basis of obtaining a contour based on the average of the data points. Its simplicity and speed give it the potential that this can be seen in factories or workshops, or even entire districts, where workers' measurements can be recorded in bulk for manufacturing of masks that are custom to that average.

## Insights

### From Research

Since the 70s, the US ramped up its occupational safety efforts within a couple of decades almost setting a global-benchmark, whereas India had made a little progress in the same period.<sup>59</sup> Laws, access to and knowledge of PPE are intertwined - where strong policy on labor laws can affect both the knowledge of PPE and the markets, almost as if in a trickledown effect - these three can be considered to make up the culture of safety in a society. The effects of this are evident in the knowledge an average person has about safety rules, practices and equipment - even within a country, differences arise between native labor and immigrant labor groups.<sup>60</sup> <sup>61</sup> The knowledge is also affected by training, communication or regulation. This education is often backed by the major PPE manufacturers

<sup>59</sup> Saha 2018

<sup>60</sup> Korkmaz 2018

<sup>61</sup> Mekkodathil 2016

which incentivizes sales, whereas there is no such initiative in India. Cultural disinterest towards personal protection ultimately affects the investments and manufacturing of PPE, by which access and availability are also further affected.<sup>62</sup> The reverse too is observed where market demand leads to the creation of stronger worker safety laws and policies,<sup>63</sup> this has been demonstrated in the case of India with increased foreign investments in the recent years, where the culture of safety from developed countries is slowly making its way into influencing the policies. With groups from developed nations also attempting to understand and educate,<sup>64</sup> one could safely state that safety is a two-way street.

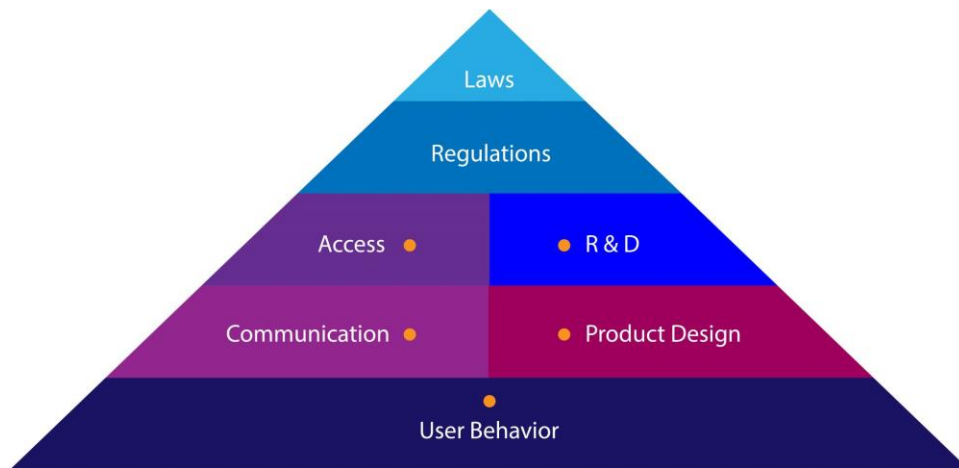


Figure 21. Hierarchy and interactions of factors key to PPE use and implementation – a design solution must target the factors highlighted

(Photo: Author)

The nascence of respirator protection guidelines in India pale in comparison to the detailed regulations and framework in the US. But even with the regulation and oversight, the issues and the solutions thereof are in a deadlock, where there is a gap between the priorities of the research groups and the needs of the users. While the issues faced by actual users and the prevalent alternatives they use are not ‘certified’, and thus not considered for their certain superior qualities (even if they fail at filtering properly), the data collected pertaining to user issues from studies and inspections becomes limited to the domain of approved products. Designing a product which closely interacts with the human body as how a respirator does, that too for any scale of production, is a challenge. This only gets more difficult when it must seal but also allow for different degrees of freedom around the nose, mouth and jaw. Also, the testing and design models for certification and research are on static setups in laboratories with emulated biophysical processes in highly controlled environments which further distance the development from the user.

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<sup>62</sup> Hart 2018

<sup>63</sup> Bill No. 186, Lok Sabha, Indian Parliament 2019

<sup>64</sup> Coulter 2009

Another phenomenon arising out of the gap in safety culture is the concentration of research and development in a handful of nations which skews the anthropometric data towards their local population.<sup>65</sup> It also affects the design and manufacturing processes which are feasible for the infrastructure and resources available to the developed countries - in this case, design, regulation and economy are heavily intertwined. Other considerations of geography, climate, economy and cultural outlook also become necessary if effective workplace respiratory protection is to be implemented globally. The design and development of a respirator or a mask has become an engineering pursuit focused on human factors and filtration, but not the user experience even when research related to respirator use and issues thereof repeatedly points to something as unquantifiable as comfort. New development paradigms rooted in the contemporary approach of design, thus, become necessary.

With comfort being at the center of most user behavior when it comes to respiratory PPE, most errors in use or incorrect practices can be linked to it. The other reason for failure at the user's end can be attributed to miscommunication or lack of training - gaps in knowledge. There is also the assumption by manufacturers that the respirator will be used in certain ideal conditions, which is the result of the current development and testing method we mentioned. Even in the most sophisticated of respirator designs, a single incorrect step in its use, maintenance or storage can undermine the protection it is meant to provide. For most general applications with reduced hazard, where respirators or masks are being used, comfort can be given the higher priority. While lack of training would be high in nations with weak labor safety rules, miscommunication and behavior compensating for comfort is common across all groups. This is also the reason that alternatives also are always present even in developed countries in

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<sup>65</sup> Lee 2013

situations without oversight.

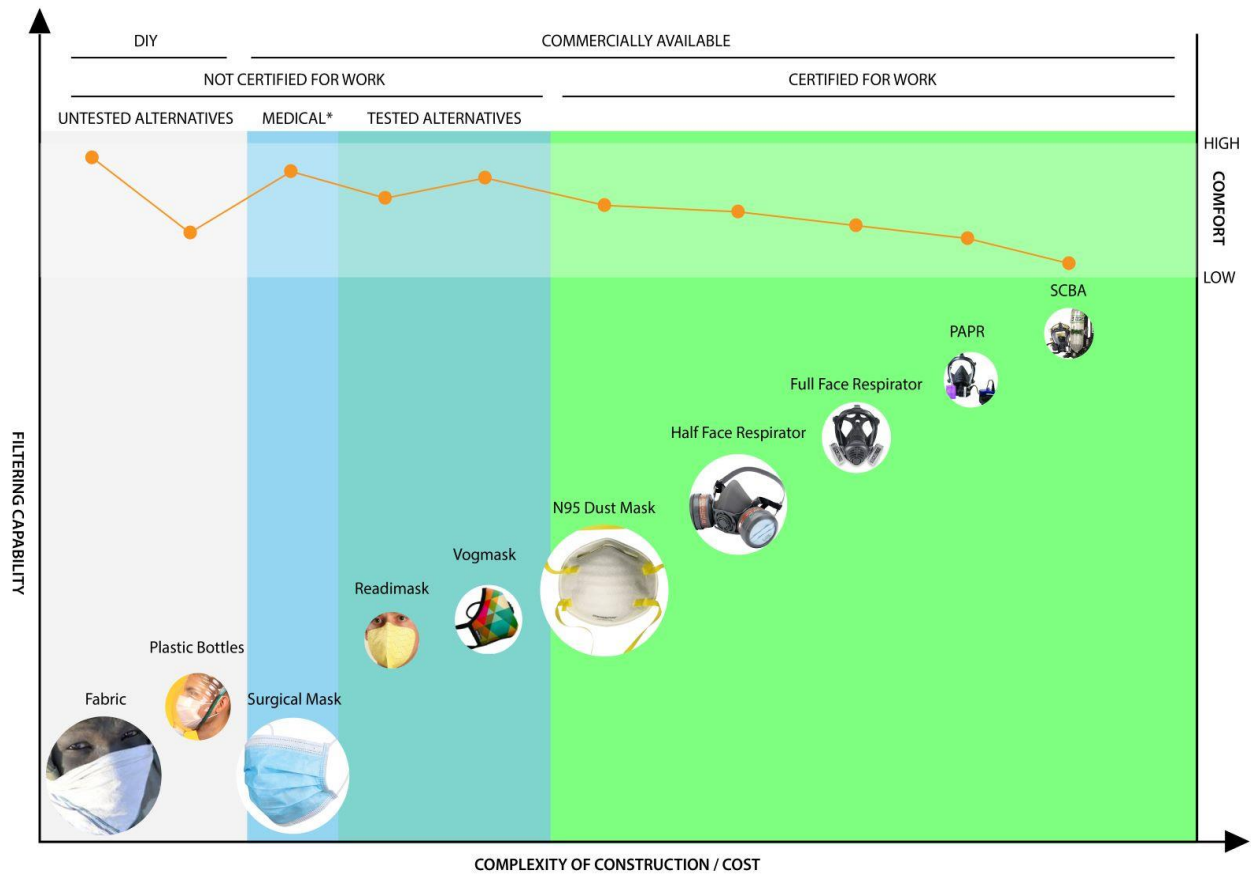


Figure 22. Comparison of different respiratory protection methods w.r.t. key identified factors – circle size shows prominence in use  
(Diagram by Author)

A reason why alternatives, despite their prevalence, might not be considered seriously by the regulatory groups is that there is some risk of legitimizing an ineffective solution. Adding to that the ability of the users to make their own respiratory PPE and unnecessary legal issues might arise. The design and development process in itself are a long process with every component tested for multiple requirements other than just filtration. The competitive compartmentalization of development groups between companies and countries prevents inter-use and interchangeability between respirator components of different brands which doesn't benefit the user, nor does it simplify the system for them.

Material challenges exist in finding the right filter which forms to a face's contours, is structurally sound, chemical resistant, maintains a seal, yet is breathable and lightweight. Material also affects the form, which affects the design of other components that might be removable or reusable - it also affects factors like collapsibility, weight and storage. The dead air space within the mask might also lead to an impact in user's performance and comfort,

hence, the facepiece can neither be too spacious nor too close to the skin. Interactions with other PPE, cross-contamination and the performance of meticulous tasks with the respiratory PPE also need to be looked at closely.

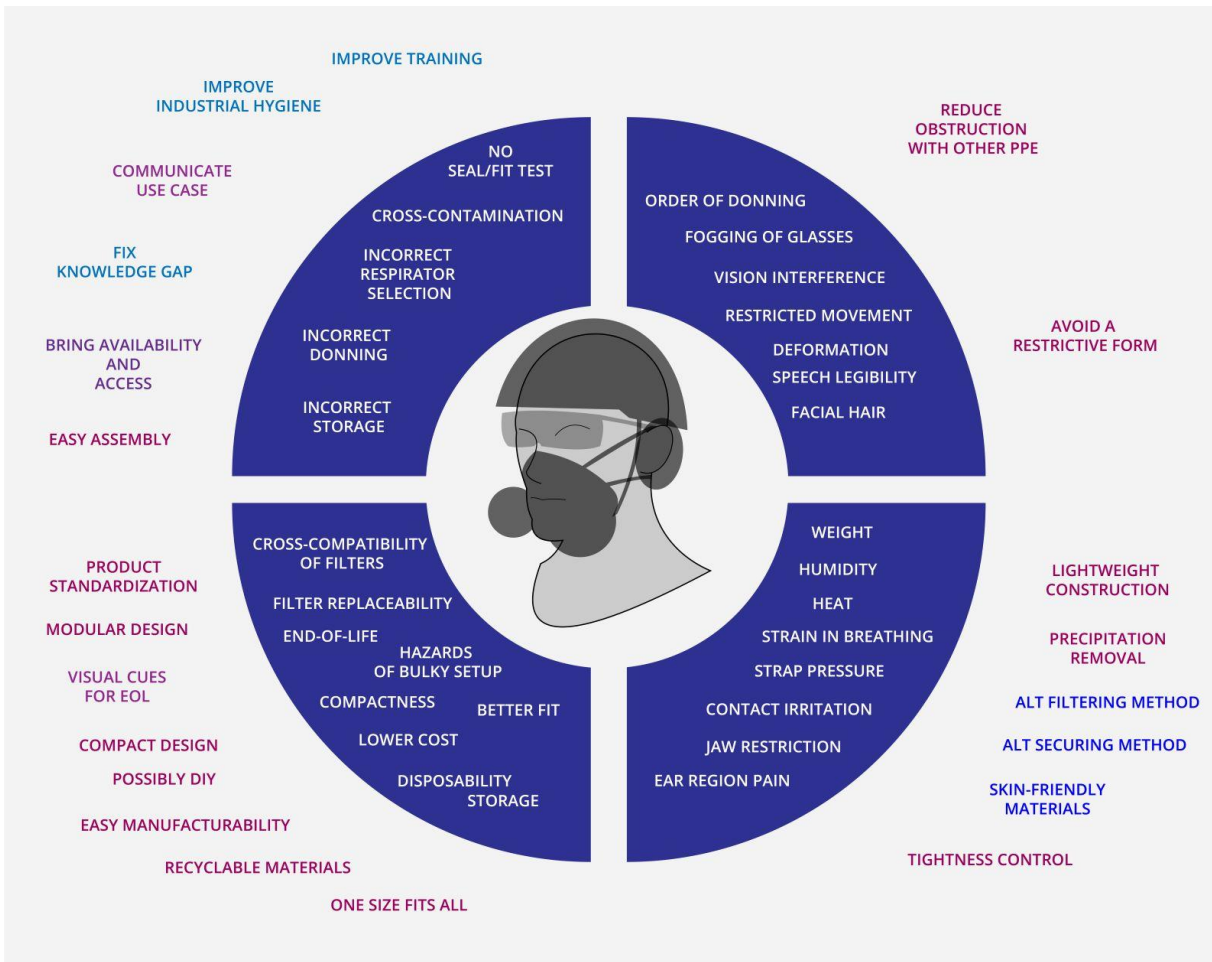


Figure 23. Visualizing all the user issues and their reasons (Diagram by Author)

There is also the aspect of communication about correct respirator use and the scenarios it is meant for, as miscommunication and misunderstanding are common across the board regardless of the country in question. In inspections, subjects have often pointed out that there is no direct interaction between them and the authorities whenever a violation is observed and they are informed of it through their own supervisors. Not only that, the information material differs widely within the various standards that exist across the world. The symbols for respiratory protection are required for a site but do not explain much beyond the fact that the user needs to wear a mask.

Any PPE which is meant for reuse tends to pick up on the personality of the user. Sometimes the users themselves would personalize their equipment even if it is prohibited or impacts performance. In bigger worksites, this personalization is a necessity in recognizing one's equipment in a pile. Even though some PPE like harnesses or

hats might allow for name tags, respirators lack the retail space for such with only half space respirators having some area on the component free for the user to mark as their own with ink.

The environmental effects of single use respirators and the consumed cartridges of elastomeric respirators are significant yet not discussed that frequently. Though the authorities advise that these be disposed of a certain way, this is the weakest part of the product's lifecycle. Communication regarding disposal needs to be more prominent and the materials in respirators should be used in a manner by which the component itself can convey, in a way, which waste stream it would best end up in. Maximizing the reusable components and extending the life of the consumables is another technical challenge that can address this problem.

## A Demonstrative Pandemic

Though the scope of this thesis is not about respiratory protection in medical scenarios, a part of it does overlap what we are trying to address. Come year 2020, the outbreak of COVID-19 led to a chain of historic global events, masks became relevant and rare – respiratory protection supplies ran short and the world faced what was a scenario the author had imagined at a small factory or an isolated region devastated by forest fires. The pandemic tested and revealed the vulnerabilities of the existing systems we have learned to trust in - economic, political, scientific and social. Following the initial confusion and change of stances on the effectiveness of respirators,<sup>66</sup> the panic buying cleared the shelves off leading to black-markets<sup>67</sup> and price-gouging.<sup>68</sup> Apart from the swing in demand-supply, the event did bring about many of the shortcomings discussed in this thesis about respirators and respiratory protection.

Amidst this severe scarcity, where both governments<sup>69</sup> and people<sup>70</sup> were hoarding essential PPE because of frozen supply chains, many ingenious alternatives were spotted and so were cases of incorrect use - content for both entertainment and concern. The authorities also, for the first time, considered these alternatives seriously going as far as putting out circulars on how to make homemade masks and reuse and sterilize them.<sup>71 72</sup> Waste from the discarded single use PPEs, including masks, has already become an issue that is being brought up, with most of these surgical masks and N95s ending up in the regular waste streams because the average user is not well aware of disposing them properly.<sup>73</sup>

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<sup>66</sup> Brosseau 2020

<sup>67</sup> Winn 2020

<sup>68</sup> Heater 2020

<sup>69</sup> Togoh 2020

<sup>70</sup> Beaumont 2020

<sup>71</sup> CDC 2020

<sup>72</sup> CDC 2020

<sup>73</sup> Sangal 2020



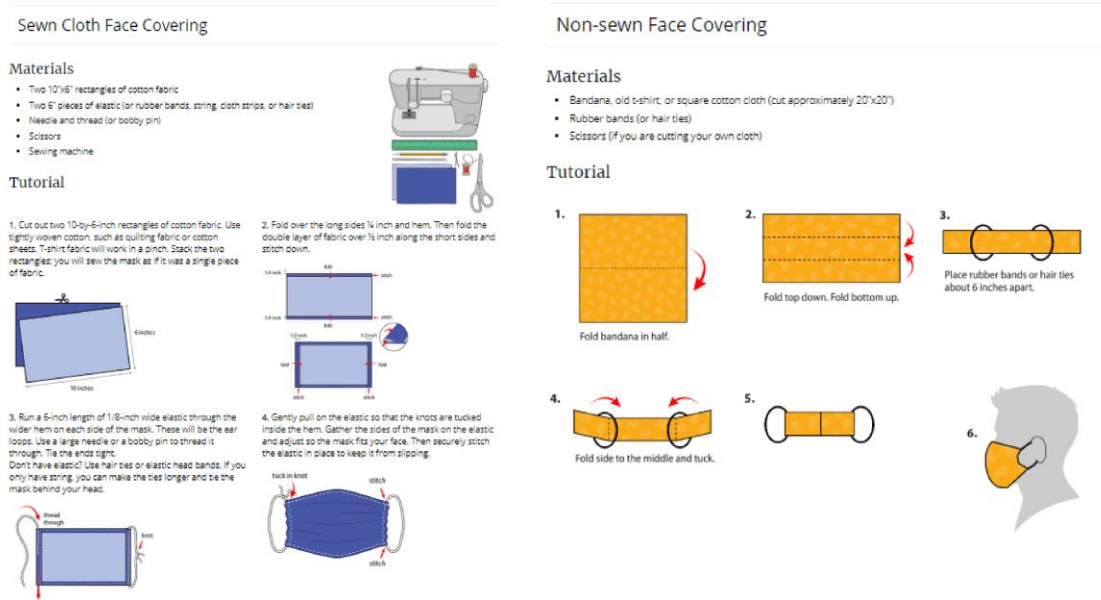


Figure 24. CDC's infographics on DIY masks for battling COVID

(Photo: Author)

It must be noted here that the use of a mask for the prevention of a flu-like illness has a different dynamic when compared to a respirator for protection in a hazardous environment, but their use overlapped and so did the issues around access and knowledge. Many solutions were actually counter-intuitive as in the case of use of valved respirators.<sup>74</sup> That said, respiratory protection came into the limelight and has led to an overall increase in people's awareness about the topic. With free DIY resources showing up, and many small-scale businesses hopping in to make fabric masks, along with mass community efforts, a part of the design and engineering community also aimed at designing a solution which could be created through technologies additive manufacturing and methods like open-sourced product development.<sup>75</sup> However, the access to this technology itself is a limited one and the respirator is a complicated part which alone cannot effectively protect unless the other parts are right. Nonetheless, these efforts proved to be useful in other open-source community efforts for ventilators and face shields.

In India, with most surgical masks running out of supply, the worst hit were the migrant labor groups who were left without any respiratory protection and stranded in big cities<sup>76</sup> - the very group whose line of work requires respiratory protection was the one to not have it during such an emergency. This made the state of the country's worker protection laws and the vulnerability of the unorganized labor sector very salient. With respiratory protection

<sup>74</sup> The Indian Express 2020

<sup>75</sup> Liberatore 2020

<sup>76</sup> Withnall 2020



becoming mandatory in public spaces, as it was in the rest of the world, the Govt. of India advised its citizens to make their own masks. The country's Prime Minister also announced in his address that while work was in progress to match up to the increased demand,<sup>77</sup> the country really did not have the infrastructural capability to produce its own PPE before this event. In an iconic gesture to encourage alternatives, the PM himself covered his mouth and nose using a cloth wrapped around his face.



Figure 25. Alternatives became the new norm

(Photo: Govt of India)

## Envisioning A Solution

Design, as a tool, aims to solve problems. And as an idealistic pursuit, it hopes for a better world where more often than not it finds itself constrained by the realities. That limitation has never stopped designers from presenting ideas for such a world. As problems in PPE usage, especially of respiratory protection, might be very complex requiring work on multiple levels, the solution here touches upon key areas which the designers of respirators should keep in mind - that the design should be cohesive to the system and every decision impacts the product's developmental ecosystem and hierarchy.

To close the gap in knowledge and access to respiratory PPE, legal reforms are a necessity, but prior to that, early steps can be taken by making respiratory protection solutions available to the worker populations in developing countries tailored to their understanding and demands. This can sow early seeds to develop a culture and an individual mindset towards safety, which is never an instantaneous process. The solution intends to do this by first opening up to the simplicity of design and the rationale behind the construction of alternatives, taking their strengths into an effective filtering implementation. It also relooks at the current developmental model and makes it open to the public, to innovate under some supervision of respirator manufacturers and regulators - this formal

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<sup>77</sup> The Tribune 2020

channel can aid both small and big businesses in the field of respiratory PPE. It frees the information from the controlled setting of a laboratory to drive key design decisions. The open sourced approach to designing a respirator, through what will be a ‘reference design’, makes it freely available for distribution and improvement. Creating an open-sourced design to bring people and the system together, produced locally it can better communicate correct use and practices, while being mindful of the user, the environment, cost, process and material.

We also intend to create a visual communication standard pertaining to respiratory protection which clearly conveys the function and intent of the respirator and also informs and educates on the correct use and its nuances in a manner which is universally understandable and language agnostic.

Also, the most cases of incorrect use occur for lower-tier respirators as these are also used for general purpose non-work-related applications and training is also usually not required for their use. Thus, our solution aims to sit in the product category of fabric masks and disposable dust masks while bringing in a lot of key functionalities of half face elastomeric respirators to that bracket. Since comfort is one of the key factors determining correct use and influencing performance and even safety, we take a truly user-centric approach where comfort ranks the highest in the problems we tackle. The decisions hence are mindful of the user’s motivations, expectations, experiences and their backgrounds rather than just reducing them to a statistic.

When it comes to the other functional aspects, we are aware that absolute sealing is difficult to attain without compromising on comfort - then again, we are aware that some break in of seal is acceptable realistically (hence the different tiers of respiratory PPE), especially for low risk large particulate situations. We also attempt to reduce the number of consumables for cost and sustainability reasons by having a respirator with a replaceable filtering component. The design also needs to be mindful of the material and the processes used - ideally, it should be something that can be made accurately with household materials, which only makes its upscaling easy in a sustainable way.<sup>78</sup>

This DIY aspect of the design will also bring previously excluded user groups into the development process as stakeholders with newer perspectives on different use-cases for other environments and ethnic groups or cultures. Bigger businesses could use the same ideas with better materials and manufacturing techniques to have more efficient PPE which cuts closer to the guidelines set by the authorities. The design solution, thus, holistically acts as a template for a new democratic paradigm in respiratory protection.

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<sup>78</sup> Bonvoisin 2017

## Design Development

### Concept Development

The initial concepts focused on a wide number of traditional and non-conventional methods of air filtration which differ from the existing and simpler methods used in respirators. This exploration offered possibilities of some industrially used methods of air filtration to be miniaturized and implemented in a respirator. Some of these methods are - electrostatic precipitation, cyclonic separation, water and fabric-based filtration. The idea was to have each method be a part of a modular system where it could be paired with the others in a cartridge-like setup. There were concerns though about the bulkiness of the setup, weight distribution and effective miniaturization of some of these processes while remaining easy to manufacture, if not DIY. The idea of a belt mounted filter was also considered with a piped supply of filtered air to a facepiece as in the case of a PAPR. This did allow for certain complicated processes to be used for filtration but this would lead to an increase in components, size and overall complexity of the solution.

Fabric wrapped in particular patterns with high surface-area also caught some interest, as it is in the case of paper-based car air filters. This would be a structure into which people could slip in a fabric of choice and tighten or loosen it telescopically to control its surface area for adsorption. Origami could also be explored for compactness but this, again, would rely on moving components and manufactured plastic parts which still would need to form an effective seal around the face somehow. The design solution had aimed to be manufacturable at different industrial scales parts which should be process agnostic, but so far, the ideas still relied on parts manufacturable by an injection mold or a 3D printer. Running into this hurdle, we started exploring the aspect of comfort, storage and the respirator's interference with other PPE.

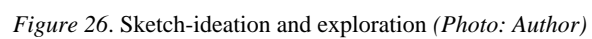




Figure 27. Repurposing PET bottles to create low resource respiratory PPE

(Photo: Author)

Frugality in material and process was the highest in simple cloth masks wrapped around one's face or the DIY anti-tear gas masks, the latter being more process and material intensive than the former. A concept of filter cartridges and face pieces by repurposing cut up PET bottles was also explored where the facepiece would be a pre-manufactured platform onto which plastic bottles with active filters could mount. This would however be a development model that relied on supplying and selling a manufactured part and was not truly DIY. Surprisingly, this mockup provided a great seal even when cut with a high degree of inaccuracy in shape. The mid thesis review feedback provided some crucial points, such as our assumption and over-reliance on the user to cut the bottles and assemble them correctly - a lot of room for error. The problem of comfort, storage and weight is still not addressed by this design as PET doesn't allow for an outlet for heat and humidity. We had also not considered the methods to comfortably secure it to the user's face. Degradation of PET was also a concern and the need of standardization for assembly would rely a lot on the different PET soda bottles available in different regions. The material and manufacture of such a mount makes it at par with a regular respirator and thus defeats the purpose. There is also the



issue of the respirator coming across as a genuine solution and rather as a hand-me-down made with trash. This design seemed to be more fit for emergency use than regular use which is aimed at impacting behavior.



Figure 28. Mockup of the conceptualized PET bottle-based system

(Photo: Author)

The author engaged in academic study on processes like additive manufacturing, plastics and injection molding and creation of form-fitting prostheses, along with understanding the details of waste management in the United States. It was understood ultimately that none of these processes would be beneficial to the design requirement.

Starting once again from scratch, our closer-to-final concept uses a cloth filter and a face forming clasp that pushes it against the face. While existing dust masks do this as well, they rely on the filter itself to conform to the contours of the face and the pressure is also on the ear. The concept shown in the pictures, using green cloth and re-purposed dust mask, demonstrates the different securing methods which imitate a muffler or a scarf - it is an intuitive way to have a cloth around one's face.

## A Case for Fabrics

Fabrics have been a recurring material in our quest for a mask design. Fabrics, though, even present as a specialized material in the approved filters are also the first choice for the layperson, whether trained or not, who does not immediately have a respirator available. This is almost an archetypical trait - a primitive yet effective use of both the material and the design, of fabric wrapped around the face, which must not be overlooked.<sup>79</sup> It isn't the use of fabric which decides the legitimacy of the protective measure but whether it is being used correctly in the right design. Regardless of what regulations say on paper, in practice and away from oversight - when it comes to

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<sup>79</sup> Scully 2017

respiratory safety, ‘some is better than none’. Even as the formal methods of respiratory protection are classified as per the use, recognition of fabric based homemade masks is absent, even when they can be an effective barrier for larger dust particulates. And with the prevalence of incorrect use in lower-tier dust masks and respirators, the author believes that the overall filtration would not be much different from the same fabric wrapping comfortably around the face. Such a fabric solution could be considered successful if even with that lack of a difference in filtration it can encourage more people to use respiratory PPE.

Fabrics are an easily available material in any region and society - the reusable/washable aspect of fabric and its relatively low cost, ease of transportation and workability, makes it a very strong candidate for this application. Its flexibility, lightweight and breathability as a material provides the greatest comfort which can give room to address other issues – the perception of fabrics when it comes to perception is superior. Though these attributes also make it a weak material for forming seals or tight fits, the right amount of layering can dilute the leakage. Fabrics can be a good visual indicator of damage and contamination - being crushed or visibly soiled compels the user to take better care of storage and maintenance as no one wants to tie a dirty cloth to their face. Certain forms can allow for folding of the fabric such that the inner area is kept isolated from the outside. This is not the case for elastomeric respirators where the perception towards the material used is different.

We already have seen fashion trends in commercially sold dust masks and it is also expected that fabric respirators will vary and be local to the area or the region of their manufacture, whether it is through form, color, process or material use - could PPE, thus, also become a cultural accessory? Also, the simplicity and low-requirement of infrastructure in manufacture also makes fabric-based mask designs ideal for emergencies.

## **Final Design**

The final design is an all-fabric system which uses a sleeved filter that is secured against the user’s face by a facepiece. The filter is layered and channeled with the outermost layer being the one meant for handling and contact. Rather than restrict the mask’s seal around a particular region, we can form an encirclement of layers, snugly packed yet loose, against the user’s skin as straps. Different methods to affix this mask to the face without having the straps going over the ear were studied and it was found that the current method is both comfortable and secure. It was also observed that the mask’s contour, which was based on a stencil from the anthropometric study, could fit different people across race and genders, thereby demonstrating the effectiveness of the method to capture and aggregate facial features of a population.





Figure 29. Development of the final design - from mock-up to high-fidelity prototype.

(Photo: Author)

## VA-U System

### The Product

VA-U is a fabric respirator consisting of a removable filter and a facepiece - it draws inspiration from a half-face respirator on how it mounts and secures to the user's face and has a filter as a separate replaceable component. The use of fabric throughout ensures a form fitting yet comfortable design and its simplicity clearly communicates its purpose and operation. Designed primarily to be accessible to anyone, as a product, it sits as a bridge in between the certified and tested respiratory solutions and the unregulated alternatives, but also strives to provide the bare minimum level of protection to the user. The design in itself serves as a template for improvisation, where the key idea is to have a user-centered product before focusing on filtration and seal. Its design is intended to be such a resource open to all for designing and developing, by opening a pathway for exchange of ideas, and involving the user in the design process.



Figure 30. VA-U Fabric-based respirator prototype

(Photo: Author / RIT Photo Services)

**Features.** VA-U's simplicity makes it stand apart from the existing products in its range - whether it is the relatively easy construction process, and low material use or the ability to understand and use the product correctly. The way this mask is used is a familiar action to everyone, almost being the archetype of a cloth serving the purpose of respiratory protection. As a design open for customization, it can quickly be altered to serve as a custom template.

It is lightweight and completely foldable which makes it compact to store and carry. Folding the mask can also keep the inner area isolated from the contaminants outside. It also allows for more breathable materials to be used for the facepiece to independently supplement a non-woven fabric-based filter. Being a fabric, it can easily convey whenever the mask components need to be cleaned or replaced. The facepiece is meant to be washed and reused, while the filter is a consumable which allows for other alternatives to be used in its place - this reduces its environmental and economic impact. The different materials also communicate the components and touch-points through contrasting colors.



Figure 31. Details of VA-U Respirator prototype

(Photo: Author / RIT Photo Services)

The bottom straps control the tightness of the mask around the face and can accommodate a variety of facial sizes - this ability also lets the user tighten and loosen the mask whenever required. Since it does not rely on affixing around the ears, it frees up that crucial area for other PPE and eliminates interference with safety goggles, spectacles, ear protection and hard hats. The layers of fabric engulf the region around the nose and mouth, acting as a buffer for leakage, while also allowing for movement of the jaw enabling communication and also letting users with some facial hair to use the product.

**Components.** VA-U consists of two main components with fasteners, nose-clip and a backing layer as sub-components for the facepiece. The material use is left open to the development group depending on the available resources and location. However, we recommend that the materials meet a minimum requirement of their function even if the aim of the design is to allow for the use of everyday materials.


The facepiece is a piece of cloth with an additional shape retaining front layer - this additional component can be replaced with a better stitching pattern on the facepiece itself. The facepiece slides through the filter sleeve and pushes the underlying filter layers against the face. The filter is a multi-layer folded non-woven fiber piece which is sealed from the sides with the outermost of layers acting like a sleeve to interface with the facepiece. The effectiveness is dependent on the number of layers, the particle size, filter surface area, air pressure and electrostatic properties of the chosen fabric. Thus, channeling the air through tight paths parallel to the filter enhances filtering action. More advanced construction could employ activated charcoal for better performance.

A soft metal nose-clip on the facepiece closes the gaps around the nose. In regular masks, a stainless-steel tab is used but folded multiple layers of softer metals like aluminium can also be used as low-cost substitutes. The fasteners, depending on the resources available, can range from velcro, buttons, elastic bands and even magnets.

The facepiece can be broken down into smaller components for better fabric use. It is advised that the filter is not stitched in any way and be sealed through thermal-adhesive operations. The prototype shown here uses felt as the main fabric for the facepiece with a heat sensitive non-woven fabric for the filter. The head straps use velcro strips and the neck strap uses magnets as fastening solutions.


**Packaging and Communication.** Since packaging is the first point of contact for the user with the mask, we have tried to design the unpacking experience to be informative yet simple. The two types of packaging make clear the differences between the two components, with use of packaging plastics only appropriate to the component which needs to be secure from contamination before use. Colored highlights, like the orange dot in this case, could point to the type of use the mask is meant for - for example, bright green could refer to a mask meant for medical use. The two information cards within the packaging visually convey the correct procedure to don the mask, its correct use and also instruct the user on how to make one. These are intended to be printed in two languages - one being English and the other being the local language to the mask's manufacturing and use. Communication firstly solves the problem of conveying to the user what the product is and what it does, this is the text and the graphics on a pack which convey the type of mask this is.

### MAKE




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# VA-U


## 1 Respirator Filter

For dust and larger particulates suspended in the air.

# वायु

## १ रेस्पिराटर फ़िल्टर

हवा में धूल तथा अन्य बड़े कणों से सुरक्षा के लिए



**Manufactured In:**  
Ghaziabad,  
UP,  
India

**May 2020**



Figure 32. The use and construction instruction slip and other communication on the product

(Photo: Author)

## The System

At the system level, there are some proposed changes which would greatly aid the introduction of respiratory safety and also the pervasiveness of protective practices across the worker population. The design and development strategy would work the best if it complements a respirator design like the one proposed. The visual information and communication related work can be implemented independently.

**Visual Communication.** Propose a family of symbols which conveys the level of respiratory hazard and the appropriate respirator type required for a scenario. This could not just be displayed on sites but on the products as well which makes matching them for the corresponding use easier. It is agnostic to language but does use wordings for certain details that cannot be conveyed otherwise. The goal is to pack as much information as possible in a visual icon, which would have otherwise been in fine print on a respirator's packaging, and would often be overlooked.

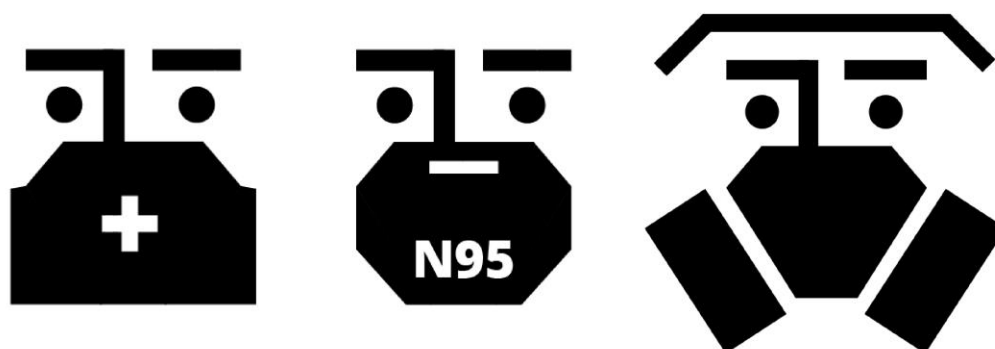


Figure 33. Proposed symbols convey different PPE usage as a visual standard.

(Photo: Author)

**Design and Development.** One of the larger goals of this design solution at a system level is that the workplace safety standard setting organizations allow for a new category of approved masks that can be made at home, even if they do not provide the same level of protection as certified products.

An online, open-to-access, repository of the respirator design details and blueprints would be the first step into implementing this.<sup>80</sup> The various sub-versions of it would have designs in different stages of approval and

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<sup>80</sup> Bonvoisin 2015

experimentation - just like how in software we have the untested/uncertified beta and the certified release version. If anyone uses certified design details to build themselves a respirator, some minimum level of respiratory protection could be considered to be guaranteed. Designers or inventors would be able to change and propose their own improvements to it and the license would also make it necessary that any significantly effective changes would have to be shared back with the community.<sup>81</sup>

Once finalized within the framework set for the template, the design is meant to be manufactured at any scale possible. As this development proceeds, there will also be a buildup of anthropometric data and a material library from various regions, both of which could be tested by the authorities at their own pace and then approved. The tried and tested designs could then also be commercially made available by businesses with access to advanced materials and processes. The same designs could also be made in cheaper materials from the database by lower-tier manufacturers to enter this market from any corner of the world.

## Impact of Work

The intended impact of this design solution is demonstrated by these imagined users and their respective scenarios:

**Gautam** is a daily wage laborer from the region of Bihar in India. Every day, he goes to town to work at a construction site for a contractor. One day, the contractor asks all of the workers to have their facial measurements taken - the process takes an hour for all forty workers in that shift. In two days, everyone on site receives a VA-U facepiece and a filter. They learn how to assemble and check them for damages and replacement. The workers are instructed to wash their facepiece regularly and they receive a new filter every 10 days. Though Gautam often forgets to wash the facepiece, the days on which he gets a new filter is a reminder for him.

**Terry** is a mechanical engineer from Pittsburgh who likes woodworking. He makes wooden toys in a small shop he has set up in his garage. For frequent sanding, he knows he needs to use a dust mask but because it gets very uncomfortable with the spectacles he needs to wear, he forgoes wearing one. His wife gifted him a VA-U and he likes how he can don one and carry out the various tasks in his shop - whenever he is sanding a part, he can tighten the mask without it interfering with his spectacles.

**Ericka** is trapped with thirty other people in her community in the wildfires of California - on the first day, the rescue helicopters dropped packages with VA-U kits. Every second day they drop new filters along with other supplies.

**ABC Group** is an industrial safety lab - they have come up with a new folding method for non-woven filters which has been shown to perform better in humid environments. ABC has its own specialized material which yields the highest result but this method also improves the characteristics of filters in other fabrics. ABC shares its findings in the VA-U open-development resource website.

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<sup>81</sup> Lanz 2019



## Tests

To test for usability, the author wore the prototype of VA-U for an hour and went to conduct various regular tasks like grocery shopping etc. Curious second looks at the mask were expected, but not in the new normal where wearing masks in public is compulsory. It was noted that the region around the cheekbones gets too close to the eyes and obscures vision at times - this can be solved by using thinner fabrics. There was no fogging observed when used with spectacles and can be attributed to the fabric's wicking and absorbing properties before the exhaled air escapes. The mask was lightweight and caused no stress around the ear or the back - the movement of the head was unrestricted in all directions. The only discomfort was the itching caused by the filter's fabric contacting the face which wasn't the correct material choice for the prototype. While donning and doffing, it was noted that the fasteners were not in direct sight of the user so knowing the locations took some time and guesses - a tactile cue thus is necessary in the design for the areas with fasteners.



*Figure 34. Testing the prototype with other PPE (left) and for prolonged durations (right)*

*(Photo: Kantha Girish)*

For communication, a quick survey was conducted on social media asking the users what they felt about the symbols designed for the information communication solution. Almost all of the users identified the symbols correctly despite having a varied level of knowledge and familiarity with respiratory protection - part of this enhanced awareness can also be attributed to the COVID outbreak.

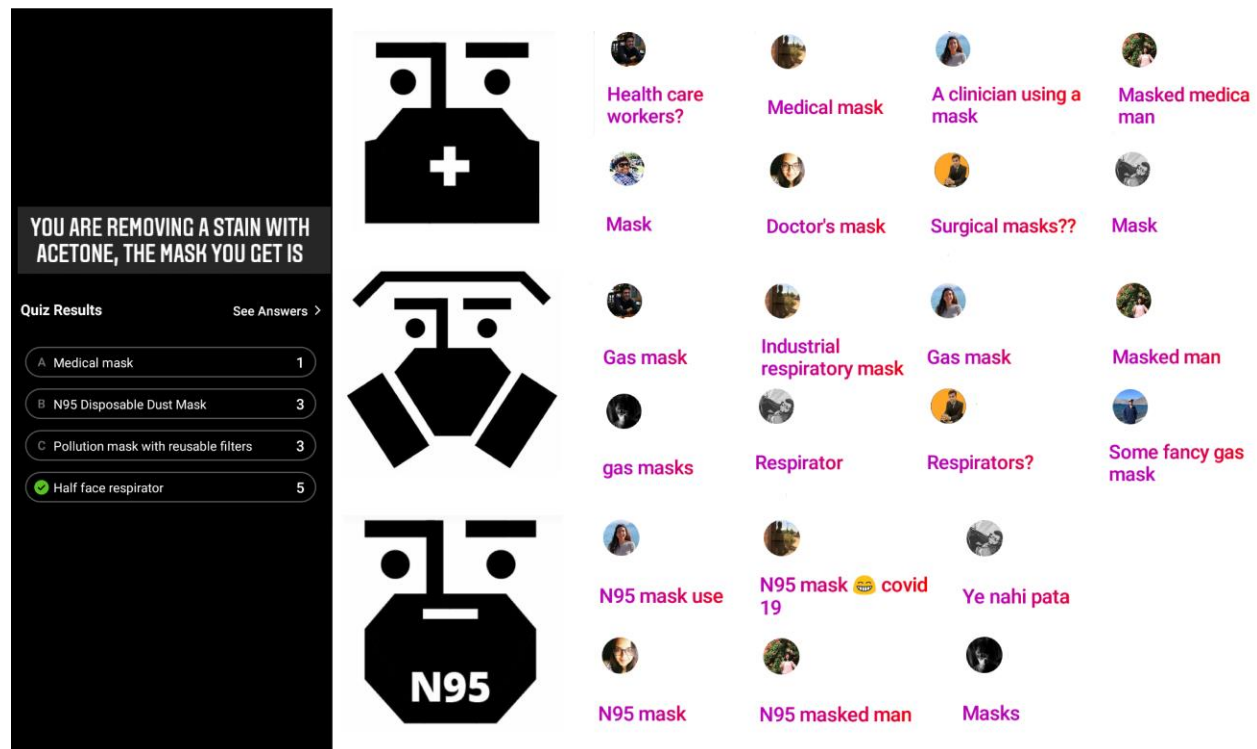


Figure 35. Survey results - conducted on Instagram, most responders recognized the symbols correctly.

(Photo: Author)

## Disclaimer

Until this design of the respirator is not tested for its filtration efficiency in a lab setting, this product should be treated as a homemade solution not suitable for a worksite. The design might be able to offer some protection against larger dust particles suspended in the air but is absolutely not to be used for vapors or toxic fumes. The author encourages that certified respirators be used for such applications.

There are also many challenges with open-development and design methods proposed. Physical product development is a time-consuming process, and for a PPE, there are many more factors that lead to delays. Maintaining an active online community with a common motivation for something that might not directly lead to economic returns is one of the known weaknesses of open source product development projects. Other challenges foreseen touch on the organizational hierarchy amongst contributors and reviews, testing and validation of a design and the legal-work related to intellectual property.

## Conclusion

In our research we have identified some of the inter-relationships between the factors leading to huge gaps in respiratory protection, in both implementation and practice. We identified three key factors which can bring about a change in a country when it comes to safety, these being - laws, commercial availability or access, and personal

outlook towards workplace safety. We also witnessed the changing attitudes towards respirators and PPE in general during the COVID-19 pandemic, which verified a lot of our observations.

By putting the needs of the users at the center, we were able to get a non-regulatory perspective on the issues and considered the uncertified, and often ineffective, yet the most common alternative solutions as product solutions with their strengths. With that, we also went deep into the regulatory side of respirators, and analyzed their design from a usability angle. One of the key takeaways was that the effectiveness of the system is very fragile, with a single incorrect step or procedure leading to the equipment being useless. Thus, we also try to address the gaps in communication at both the system and the product level - with a universal symbol system which conveys different respirators for different scenarios and a more visual instructional method respectively.

The long surviving tradition of using fabrics for respiratory protection, with a touch of design, can holistically aid in shifting the attitudes of the individuals across societies, from being reluctant to participative; through incentives like low cost, easy availability and more comfort while providing a bare minimum level of protection. Our solution, VA-U, is an open-sourced respirator design accompanied by an entire developmental ecosystem that allows for people to work directly with the regulatory authorities and manufacturers. The design opens up the dialogue for a personal protection paradigm that is fitting to the requirements of the place and the people using them. It also allows us to look at personal protection equipment not as something that can be made only by companies with powerful infrastructure but also as something that can be made by communities local to the worksite. For the developed world, where the user expectations from the PPEs are way different, this design still finds use in emergency situations.

## Further Work

Studies are needed on how this design could be implemented with existing certified respirators, especially the dust masks. Some of the proposed mechanisms, like channeled layered filtration need to be tested and evaluated against existing filters. Leakage regions need to also be identified in the design. It is also necessary that the comfort is benchmarked against other respirators through human factors/ergonomic analysis of tasks performed, in both an occupational and a laboratory setting. More detailed and controlled experiments of the studies on seal deformation and the recording of anthropometric details need to be conducted to also explore their viability in other respirator design processes.

More work is needed in creating the framework for the proposed open-source development model for this respirator - this includes the management of design versions, their approval and dissemination. There is also the need of an exhaustive material database which explores and suggests different options for the components of this design template. Involving the regulatory bodies as constructive participants is also a foreseen challenge in this idea.

Testing is required on the efficacy of the visual communication solutions suggested - whether these are truly intuitive across different cultures. We also need more studies on the interactions of users with their respiratory

PPE, on how they don and doff their respirators - details on points of contact could offer design cues on making the design be self-explanatory or even aid in isolating these regions from contaminating other parts of the masks.

Going further, similar design and development approaches could be undertaken for other respirator tiers and even for other PPE like goggles, hearing protection, gloves, hard hats etc.

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## Appendix

### Appendix A: Interview questions for Indian workers (In Hindi):

अस्वीकरण / Disclaimer:

मैं, <your name>, अपने मित्र ऐश्वर्य की पढ़ाई संबंधित अनुसंधान (रिसर्च) के वास्ते आपका इंटरव्यू ले रहा हूँ। इस इंटरव्यू में आप खुलकर अपने विचार प्रकट कर सकते हैं, सवालों के जवाब अनिवार्य (ज़रूरी) नहीं हैं - हमें ईमानदारी से आपके विचार एवं प्रक्रियाओं को समझना है। अगर आपको लगता है कि कोई जवाब आपकी या आपके नियोक्ता (मालिक) की संवेदनशील जानकारी को प्रकट करे या बुरी छवि का प्रदर्शन तो उस सवाल-जवाब को हम रिकॉर्ड नहीं करेंगे। अगर आप चाहें तो हम यह इंटरव्यू पूरी गोपनीयता के साथ ले सकते हैं - आपका नाम और शकल नहीं दिखाई जायेगी। यह आप कभी भी इंटरव्यू के दौरान, पहले या बाद में बता सकते हैं।

#### Interview Questions:

अपना परिचय दें : नाम, उम्र, किस शहर से हैं

व्यवसाय संबंधित:

क्या काम करते हैं?

कितने समय से कर रहे हैं?

इस से पहले क्या काम किया है?

परिवार में और कोई जो काम करता हो?

सुरक्षा उपकरण संबंधित: (Ask the same set of questions again with breathing masks/respirators instead of general safety equipment if the subject answers with masks in the first pass)

क्या आपके कार्यस्थल पर सुरक्षा उपकरण का उपयोग अनिवार्य है?

किस तरह के उपकरण बताये गए हैं ? (masks, gloves, suits, vest etc.)

अगर इनके बिना काम पर गए तो क्या होता है?

यह उपकरण खुद खरीदना पड़ता है या मालिक देता है ?

आपको क्या यह सब ज़रूरी लगता है या ड्रामा?

क्या आपको इनके प्रयोग की ट्रेनिंग दी गयी है?

इनके इस्तेमाल में क्या-क्या कठिनाईयाँ आती हैं?

क्या पिछली जगह में काम पर यह उपकरण की ज़रूरत पड़ती थी, वे इस जगह से कैसे अलग है ?

क्या किसी एक उपकरण से आपके बाकि उपकरण या काम पर असर पड़ता है ?

क्या आपके साथ काम करने वाले यह उपकरण पहनते/नहीं पहनते हैं? वह क्या कारण बोलते हैं ऐसा करने के लिए?

क्या आपने किसी को काम पर घायल होते देखा है/सुना है ?

क्या आपने किसी की जान उपकरण से बचते हुए देखी है / या उसके बारे में सुना है ?

क्या कोई जुगाड़ का इस्तेमाल करते हैं जिस से बचत हो या ज्यादा असरदार सुरक्षा हो ?

#### Opinions/Biases:

क्या अपने मास्क या कपड़े को एक बार बनाते या पहनते हुए दिखा सकते हैं? (record)

यह क्यों असरदार है - किसने सिखाया / बताया? (know their opinion on why it is good enough even when they know it is not perfect)

दूसरे लोग इस उपाय को कैसे अपनाते दिखे हैं?

क्या इसको लगाने का गलत तरीका भी है जिस से यह काम का नहीं रहता ? लोगों को क्या-क्या गलतियां करते देखा है सांस संबंधित सुरक्षा के मामलों में?

सेहत संबंधित:

क्या आपको न्युमोनिया या दमे की बीमारी हुई है? कितनी बार |

क्या आपको छाती में जकड़न, घरघराहट या खांसी अक्सर रहती है?

क्या आप धूम्रपान करते हैं ?

क्या कभी काम पर या काम के सीधा बाद सांस फूली-फूली सी लगती है ?

क्या परिवार में काम करने वालों को कोई ऐसी बीमारी या परेशानी है ?

क्या आपके साथ काम करने वालों को कोई ऐसी बीमारी या परेशानी है ?

## Appendix B: Survey questions for Indian markets and business establishments:

### Market Survey on Availability of Respiratory PPE in India

#### Aim:

The aim of this study is to study and record the availability of respiratory protective equipment like dust masks and respirators. The areas of study are local markets and shops in India that might stock such equipment. We want to study the percentage of shops that stock these, the type of mask which is stocked the most and the level of knowledge of the dealers regarding respiratory protective equipment.

#### Preliminary Instructions:

Look for and mark the hardware stores and construction-carpentry material dealers around in your area or the market you plan on visiting next.

#### Survey Brief:

Since most people do not know the exact differences between dust masks and other PPEs, you will have to ask in the simplest language about 'masks' or 'dust masks' or 'paint spray masks'.

The business should ideally stock these two kinds.

(L to R) A disposable dust mask, a half face respirator and a full-face respirator

You might also be shown surgical masks (as shown below) which are not protective equipment. But do note the instance if this happens. Details of noting these along with other fields in the table is given in the following page.

#### Entering the Data:

Shop Type - Note whether the shop was primarily a hardware store, a supplier of protective equipment, or even a medical store.

Terms Used - Note the terms you used to convey that you were looking for a mask.

Types Available - We will be assigning types to the masks for ease in filling out the form.

Type A: Disposable dust masks (they do not have replaceable filters)

Type B: Half face respirators

Type C: Full face respirators

Type M: Medical masks (they do not have replaceable filters)

Type X - Other alternatives or local solutions (note the name etc.)

Show/Sales - note the priorities between showcase and sales for each type. Ie. If the storekeeper shows you two masks, note which one he showed first (priority 1) and then note which among the two sells more.

Filter Available - Ask if they stock filters for the given type. If yes, mark as Y; if no, mark as N; if the mask doesn't have a replaceable filter, mark with X.

Qty/Cost - Note the amount that is sold and the cost. If a mask is sold loose and individually, the quantity will be 1 whereas if it is sold only in a box of 100, the quantity will be 100 with the price of the box as the denominator.

Notes - Note anything interesting you feel that happened while inquiring about the masks or a specific type.